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Lateral Coherence and Mixing in the Coastal Ocean: Adaptive Sampling using Gliders

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LONG-TERM GOALS

Lateral mixing is driven through the interplay between finescale isopycnal stirring (shear + strain) and small-scale diapycnal turbulence. We seek to understand this interplay within highly anisotropic coherent structures, such as fronts, jets, eddies and filaments, which likely control lateral dispersion in both coastal and open ocean. These structures evolve yet are often persistent on O (3 day) timescales, so are ideally suited to be adaptively sampled by autonomous gliders that actively report both turbulent and finescale statistics.

OBJECTIVES

As part of a coordinated effort to quantify the meso- through micro-scale processes driving lateral dispersion, we plan to deploy 4 AUV gliders to perform intensive, adaptive surveys. Newly-enhanced to measure turbulent mixing, water-column currents and dye concentration, these OSU autonomous gliders will capture the interplay between shear, strain, and turbulence over a wide range of scales. In conjunction with ship-based dye release experiments, adaptive glider sampling will substantially increase the synoptic coverage of the dye surveys, providing a more complete description of the spread and dispersion of the dye. Microstructure sensors will allow for the quantification of small-scale mixing and its dynamical feedback to meso and sub-mesoscale flows. ADCP imaging of water-column velocity will (i) characterize the features driving fluid dispersion, (ii) help build better turbulence parameterizations in anisotropic environments, and (iii) will provide enhanced tracking capabilities for lateral coherence calculations. The scarcity of synoptic observations in the past has made it impossible to detangle the lateral and vertical processes. Adaptive sampling with multiple gliders in multiple locations for extended durations will provide the detailed statistics necessary for the community to make progress.

APPROACH

We plan to deploy four newly-enhanced, autonomous gliders to measure the lateral coherence and evolution of dynamically significant properties. These properties include velocity (U), velocity shear

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(dU/dz), stratification (N2), temperature (T), salinity (S), temperature variance dissipation rate (χ), turbulence dissipation rate (ε), turbulence diffusivity (K_T), biological fluorescence, and, in cooperation with a dye release experiment, dye concentration.

OSU enhanced gliders are ideal sampling platforms for multiple reasons:

- Because they incorporate acoustic Doppler current profilers (ADCPs) with bottom-tracking capabilities, these gliders will be tracked while below the surface, permitting continuous spatial coherence computations on horizontal scales spanning O (10 m – 10 km). Gliders will also be equipped with a six component gyro package (3 linear and 3 rotational rate sensors) which will provide enhanced navigational capabilities at water depths where bottom-tracking is unavailable. All navigational data will be post-processed in a full LADCP-type inversion (i.e., Visbeck, 2002, Nash et al 2007) that utilizes all ADCP, gyro, and GPS data to provide both water-column velocity and vehicle location/speed.
- Because all data are logged and reported back on a regular basis, all data (including velocity and turbulence data) will be incorporated into the adaptive sampling that will be necessary to track laterally coherent features. This will be the first use of turbulence data for guidance of autonomous vehicles using adaptive sampling
- Because each enhanced glider possesses measurement capabilities similar to that obtained during a single shipboard microstructure operation (albeit slower), a fleet of 4 enhanced gliders operating independently will both (1) sample more mixing/dispersion "events" from a statistical perspective, and (2) provide simultaneous observations at multiple locations – necessary for coherence calculations. The strength of this measurement is in addressing the interactions between isopycnal stirring via measurement of lateral coherence of dynamically significant aspects of the flow field and diapycnal mixing via direct turbulence measurements.

WORK COMPLETED

Tests were conducted in June 2009 (internal pod) over Stonewall Bank on Oregon's continental shelf with the two existing microstructure gliders. These were coordinated with Chameleon turbulence profiling. An engineering test cruise was completed in July 2010, in which the glider successfully flew a fixed pattern relative to a moving drifter.

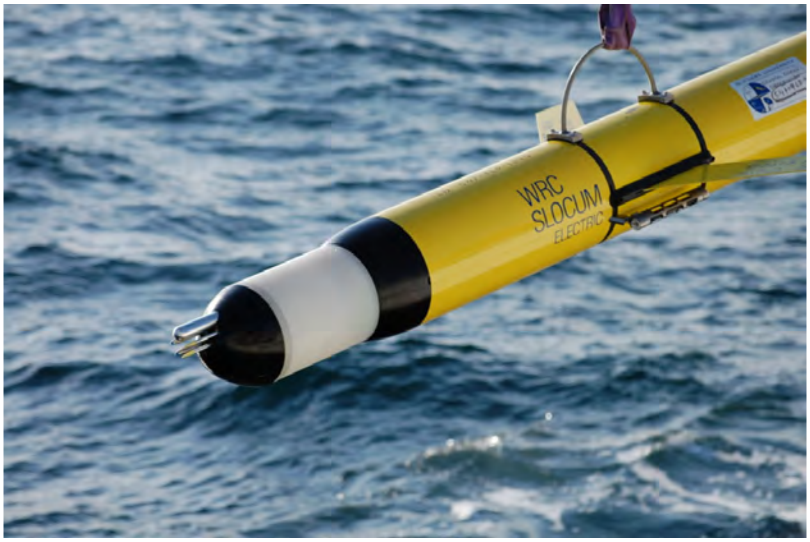

Figure 1 – Photograph of Webb glider with internal turbulence pod.

LatMix 1 Main Field Experiment

The plan was to deploy 4 gliders, and fly a coherent survey pattern relative to a moving drifter that marked the approximate location of the large rhodamine dye patch. We planned to survey dye releases at two sites: 1. low-energy , weak strain ('the big nothing') and 2. medium-energy, moderate strain ('filament or front'). The coherent survey pattern for the gliders was a tic-tac-toe with two gliders running parallel lines separated by 4 km (e.g., north to south) and the other two gliders running perpendicular lines (e.g., east to west). We also planned to fly the gliders in a circuit around four EM-APEX floats. We planned to deploy a fifth glider to make deep (1000 m) cross-sections to characterize the mesoscale structure. The goal was to resolve the evolution of submesoscale structures in the dye patch and provide complimentary observations to the ship-based (RV Endeavor) MVP surveys.

Two gliders (350 m Webb Slocum) were equipped with CTD (SBE 41), single wavelength backscatter, chlorophyll, and rhodamine fluorescence (WETLabs FLBBRH), fluorescein fluorescence (FLUR), and 600 kHz phased array DVL (RDI) – gliders john (unit 185) and june (unit 186). Two gliders (200 m Webb Slocum) were equipped with CTD (SBE 41) and homemade microstructure package with two thermistors, two shear probes and a six port pressure sensor 'gust probe' – gliders doug (unit 93) and russ (unit 91). A fifth glider (1000 m UW Seaglider) was equipped with CTD (SBE 41), dissolved oxygen (SBE 43), single wavelength backscatter, chlorophyll and colored dissolved organic matter fluorescence (WETLabs FLNTU?) and photosynthetic active radiation (Satlantic ?) sensor – glider sg158.

Setup (May 29 –May 31)
We loaded and secured the gliders and equipment. We setup a 'command central' in the ship's dry lab with four laptops. Glider communications and functions were tested on deck. With help form Ledwell's group, we performed a calibration of glider june's rhodamine dye sensor in her shipping crate.

Transit and Site 1 Selection (June 1 – 2)
We departed 0900 EDT June 1 and headed southeast toward Site 1 about 250 nm away. On site, all three ships performed a coordinated 'star pattern' survey to assess the large scale characteristics, and determine a suitable location for the Site 1 deployment. Glider sg158 was deployed at 31.5937N, 73.4186W and sent to the NE, repeating a section from the large scale survey.

Site 1 (June 2-10)
Gliders june, john, doug and russ were deployed during the the EM-APEX array deployment, on the outer 2 km radius ring with june and doug deployed at the northern point and john and russ deployed at the eastern point. Gliders surveyed the tic-tac-toe pattern continuously, except june who was briefly recovered twice (June 5 and 8) to correct a ballasting and flight problem.

The central drifter followed a large scale clockwise path (with some inertial oscillations superimposed) for about five days, and then accelerated to the southeast over the last day. Typical drift speeds were 10 – 20 cm/s, increasing to 30 – 40 cm/s. Most gliders were able to maintain their individual lines relative to the moving drifter to within 1 km. At site 1, the gliders were able to complete 9-10 sections.

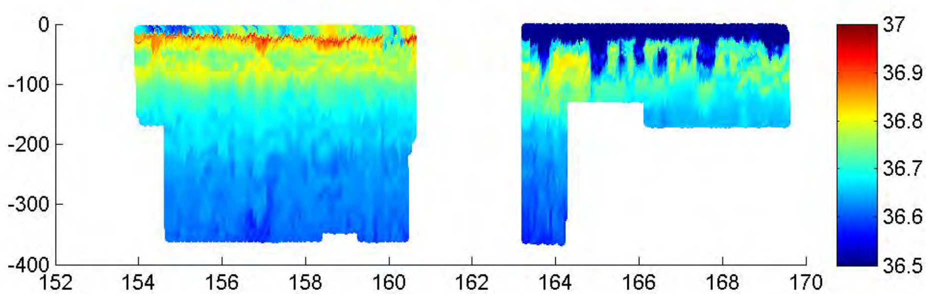

Figure (2): Salinity observations from glider john during both deployments (x-axis day of year, y-axis depth in meters). At site 1 there was an abundance of submesoscale structure near the pycnocline, characterized by local maxima that may or may not show a connection to the surface. At site 2, salinity was fresher by 0.3 and structures typified by salinity minima extending vertically down from the surface layer.

The glider observation showed submesoscale structure in the salinity field at the pycnocline consistent with features seen in the MVP observations. The features appeared as local maxima in the salinity field sometimes connecting up to the surface layer. Observations below 100 m also showed submesoscale structure in the salinity field, but less intense than the pycnocline variability.

Transit and Site 2 Selection (June 10 – 13)
We departed Site 1 heading northwest to survey a strong surface temperature front. Velocity and strain at the front were too strong for Site 2 constraints (95 cm/s and greater than 1.e^-4 s^-1). We reoriented to the southeast surveying a cold filament and apparent warm meander with flow following a clockwise path. We located a stagnation point with southward flow on the west and northward flow on the right. We deployed sg158 north of the stagnation point and sent it southwest crossing the warm front.

Site 2 (June 13 – 19)
We launched june, john, doug and russ during the EM-APEX deployment. This time we deployed the gliders at the center of the array (approximately with the center of the rhodamine release). Gliders again surveyed a tic-tac-toe pattern relative to a drifter marking the center of the rhodamine dye patch. All gliders surveyed continuously. Glider Russ had difficulty keeping up the other gliders and lead drifters (unclear as to why).

Site 2 was characterized by a strong jet (50-60 cm/s), flowing northwest, and there was a surface temperature front with warm water west of the jet and cool water east. Later the temperature structure resembled a filament with a local maximum in the temperature field within the current jet. Salinity in the jet was lower than the surrounding water. Gliders john and june observed coherent dye structure frequently during the site 2 survey.

Transit Home (June 20 – 21)

RESULTS

The gliders successfully flew fixed survey patterns relative to moving drifters in both the low energy (20 cm/s) and medium energy (70 cm/s) field sites. Successful glider-based ADCP observations were collected during both experiments and we're developing an algorithm for processing the ADCP data into full depth profiles of absolute velocity, using techniques borrowed from LADCP data processing.

IMPACT/APPLICATIONS

Gliders offer a means of making two very valuable types of relatively autonomous measurements in the ocean. The first is the type of repeated routine observation that permits establishment of a climatology from which significant deviations can be identified and addressed. The second is the observation of extreme events (such as hurricanes) that cannot be made from ships. We have established standards of ocean turbulence measurements and have extended our ship-based vertical and horizontal profiling packages to moored mixing measurements. It has been a natural evolution to use this expertise to integrate new sensors into gliders that will both begin to define climatologies of mixing in coastal waters and lead to turbulence measurements in events such as hurricanes for which we have limited or no observation.

PUBLICATIONS

Shearman, R.K., J.D. Nash, P.J. Wiles, J.N. Moum, J.A. Barth, and S. Glenn, 2011. Glider observations of pycnocline mixing over the Mid-Atlantic Bight induced by Tropical Storm Hanna, in draft form for *Geophys. Res. Lett.*